Psychometric properties and reference values for the ImPACT neurocognitive test battery in a sample of elite youth ice hockey players

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Abstract

This cross-sectional study aimed to determine psychometric properties and reference values for ImPACT in a sample of 704 elite ice hockey players aged 13-17. Baseline ImPACT tests were completed at the beginning of the 2011-2012 season. Players aged 16-17 had better visual motor processing speed (adjusted $R^2 = 0.0522$, $F(2, 45) = 10.79$, $\beta = 2.87$, $p<0.001$) and impulse control (adjusted $R^2 = 0.0185$, $F(2,45) = 7.46$, $\beta = -1.35$, $p=0.001$) than younger players, and females had greater total symptom ratings than males ($z = -3.47$, $p = 0.0005$). There were no other sex- or age-related differences in neurocognitive performance, and no effect of previous concussion on ImPACT scores. Reference values with cut-off scores are presented.

Key Words: concussion; pediatric; neurocognitive assessment; ice hockey

Introduction

Concussion is the most common specific injury type in youth ice hockey (Emery, Kang, Shrier, Goulet, Hagel, Benson et al, 2010; Emery & Meeuwisse, 2006). It reportedly accounts for 15-18% of all injuries sustained in adolescent age groups, with estimated incidence rates of 0.82 to 2.70 concussions per 1000 athlete exposure hours in the most elite divisions of play (Emery et al, 2010; Emery & Meeuwisse, 2006; Honey, 1998). With increasing concern about the potential long-term consequences of concussion in these young players, there is considerable interest in the development of standardized screening, diagnosis, and management procedures (McKeever & Schatz, 2003).

Significant variations exist in premorbid cognitive functioning and subjective symptom reporting. As such, concussion management programs may strive to include a baseline evaluation of these factors. However, baseline testing is resource-intensive and is not always feasible. It is therefore important to establish population-specific normative ranges for baseline test scores to aid in clinical decision-making in the absence of individual baseline assessments. The Immediate Post-Concussion Assessment and Cognitive Test (ImPACT) is a web-based neurocognitive test battery that is commonly used for baseline and post-concussion assessments of youth athletes. The psychometric properties of the test have been examined in other sport populations. For example, Schatz & Sandel (2013) determined that the web-based version of ImPACT had adequate sensitivity (91%) and specificity (69%) during the acute states of concussion management among high school and college athletes. Elbin and colleagues (2011) found the intraclass correlation coefficients of the 5 index scores of ImPACT over one year ranged from 0.62 to 0.85. Yet, the use of neurocognitive testing is still being debated in the scientific literature with a call for increase data to support the psychometric properties of instruments like ImPACT (Randolf, McCrea & Barr, 2005).

There are a number of factors that have been identified in the literature which must also be considered in the context of cognitive testing for elite youth ice hockey players (Iverson, Gaetz, Lovell, & Collins, 2005; Podell, 2004; Lovell, Collins, Iverson, Field, Maroon, Cantu et al, 2003; Iverson, Lovell, & Collins, 2002; Lovell, Collins, Podell, Powell, & Maroon, 2000; Maroon, Lovell, Norwig, Podell, Powell, & Hartl, 2000). Specifically, it is understood that adolescents mature cognitively with increasing age and, consequently, improved performance on neurocognitive tests has been reported (Gioia, Janusz, Gilstein, & Iverson, 2004; Maruff, Collie, Anderson, Mollica, McStephen, & McCrory, 2004). There are also established sex-related differences in test performance, with females reportedly scoring higher on verbal memory tests, while males reportedly score higher on visual memory tests (Covassin, Swanik, Sachs, Kendrick, Schatz, Zillmer et al, 2006). Female athletes, particularly those with a history of previous concussion, typically endorse a greater number of symptoms at baseline than male athletes (Kontos, Elbin, Schatz, Covassin, Henry, Pardini et al, 2012; Schneider, Emery, Kang, Schneider, & Meeuwisse, 2010; Shehata, Wiley, Richea, Benson, Duits, & Meeuwisse, 2009; Covassin et al, 2006). The interpretation of ImPACT results for youth athletes should therefore be made on the basis of demographically (i.e., age and sex) adjusted percentile scores.

Furthermore, concussion history has been considered in the context of baseline testing. Considering studies examining the effect of previous concussion on neurocognitive performance in children, adolescents, and young adults, some have demonstrated no effect (Brooks, McKay, Mrazik, Barlow, Meeuwisse, & Emery, 2013; Theriault, De Beaumont, Tremblay, Lassonde, & Jolicoeur, 2011; Broglio, Ferrara, Piland, & Anderson, 2006; Iverson, Brooks, Collins, & Lovell, 2006; Thornton, Cox, Whitfield, & Fouladi, 2008; Bijur, Haslum, & Golding, 1996), while others have reported lingering neurocognitive deficits (Elbin, Covassin, Hakun, Kontos, Berger, Pfeiffer et al, 2012; Iverson, Echemendia, LaMarre, Brooks, & Gaetz, 2012; Moser, Schatz, & Jordan, 2005; Gaetz, Goodman, & Weinberg, 2000) There is also evidence that those with a history of previous concussion demonstrate increased total baseline symptom ratings (Iverson et al 2012; Thornton et al, 2008; Moser et al, 2005; Brooks et al., 2013), but there is a paucity of information regarding which specific symptoms are typically endorsed by these athletes. Given the high rate of concussion in youth ice hockey, determining the effect of concussion history on symptom reporting is crucial to the establishment of population-specific baseline ranges.

The purpose of this study was to determine the population-specific reference values and psychometric properties of the ImPACT test in the context of elite youth ice hockey. The parameters under investigation included mean, median, and range values for each of the ImPACT composite scores. In addition, information will be presented that allows for clinical interpretation of composite and symptom scores.

Methods

Study design and participants

As part of a larger cohort study, cross-sectional data were collected during a baseline assessment prior to the commencement of the 2011-2012 season for ice hockey players competing in the most elite divisions (AA, AAA) in two Canadian cities. Inclusion criteria were the following: male or female players; aged 13-17 years through the season of play (a small number of Bantam players were 12 years old at the time of baseline testing, so they were excluded from analyses); written informed consent to participate (player and one parent or guardian); players registered with hockey associations in the two target cities; players participating in the Bantam (13-14 years) or Midget (15-17 years) age groups only; players in elite divisions of play (AA, AAA); agreement of the player's head coach to participate in the study; and agreement of the team therapist to collect information about individual player participation and injury throughout the season as part of the larger cohort study. Players were excluded if they had sustained a previous injury or had a chronic illness that prevented full participation in hockey at the beginning of the 2011-2012 season (e.g., they were injured at the time of baseline testing).

Written informed consent was obtained from each player and a parent or guardian. Approval for this study was granted by the ethics boards at the participating universities.

Baseline testing was conducted by team at the university sport medicine clinics. At these sessions, players completed the ImPACT test on individual laptop or desktop computers with an external mouse under the supervision of a research assistant. Up to 10 players completed the ImPACT test simultaneously, and the testing environment was kept as quiet and free from distractions as possible.

Outcome measure

The ImPACT battery is a web-based computer-administered neurocognitive test developed for the assessment of sport-related concussion in youth, collegiate and professional athletes. The test takes approximately 30 minutes to complete, yielding five composite scores for visual memory, verbal memory, visual motor processing speed, reaction time, and impulse control. ImPACT also provides a total symptom score, based on ratings of 22 common post-concussion symptoms on a scale from 0 (none) to 6 (severe). The test is designed to minimize practice effects through the use of several alternating forms (ImPACT Applications, 2011), and has previously been used for baseline and post-concussion assessments for youth ice hockey players.

For the purpose of this study, concussion history was derived from the demographic portion of the ImPACT test, where players are asked to self-report the number of previous concussions that they have sustained.

Analysis

Stata version 12.0 was used for all statistical analyses. Analyses included those who reported attention deficits or learning disabilities, as the sample prevalence of attention deficit and learning disability (3.2 - 4.4%) was consistent with population prevalence estimates (American Psychiatric Association).

Multivariate linear regression, adjusted for cluster by team, was conducted to examine the effect of age, sex, and concussion history (i.e., yes/no previous concussion) on baseline ImPACT composite scores. Wilcoxon rank sum tests were conducted for data that were not normally distributed. McNemar's chi square (χ^2) was used to compare proportions of participants who reported specific baseline symptoms.

Raw composite scores for visual memory, verbal memory, visual motor processing speed, reaction time, impulse control, and total symptoms were stratified by age group and sex to be consistent with previously published normative value tables. A conservative Bonferroni correction was applied to all analyses to account for multiple comparisons (0.05/17), resulting in an acceptable alpha of p = 0.003.

Results

Of the 768 players recruited for the larger cohort study, 743 (96.7%) completed the baseline ImPACT test. Of these, 37 players (5.0%) were excluded based on an invalid test (as flagged by the ImPACT program) and two players were excluded because they were 12 years old at the time of baseline testing; 704 (95.0%) were therefore included in the analysis. Characteristics of included players are presented in Table 1. Players excluded for invalid tests (males: n=25 aged 13-15, n=8 aged 16-17; females: n=3 aged 13-15, n=1 aged 16-17) did not differ significantly from included players in demographic characteristics, concussion history, or reported attention or learning issues.

Baseline composite scores for males and females are presented in Table 2. There was no significant effect of age, sex, or concussion history on visual memory, verbal memory, or reaction time composite scores (Table 3 and Table 4). Although there were no significant effects of sex or concussion history, players aged 16-17 scored better in visual motor processing speed (adjusted $R^2 = 0.0522$, $F(2, 45) = 10.79$, $\beta = 2.87$, $p<0.001$) and impulse control (adjusted $R^2 = 0.0185$, $F(2,45) = 7.46$, $\beta = -1.35$, $p=0.001$) compared to players aged 13-15.

Females reported a significantly higher total symptom score (median = 5; interquartile range [IQR]: 1-13) than males (median = 3; IQR: 0-7) at baseline ($z = -3.47$, $p<0.001$) (Figure 1). Players aged 16-17 had a significantly higher symptom score (median = 4; IQR: 1-10) than those aged 13-15 (median = 2; IQR: 0-7) ($z = -3.22$, $p = 0.001$), but there was no significant difference by concussion history (no reported concussion: median = 3; IQR: 1-8, reported previous concussion: median = 3; IQR: 0-8) ($z = 0.27$, $p = 0.79$). The most commonly reported symptoms were “trouble falling asleep” (41.3% males, 45.1% females), “sleeping less than usual” (30.6% males, 43.4% females), and “fatigue” (25.7% males, 38.1% females).

Based on overlapping confidence intervals, the proportion of males aged 13-15 reporting individual symptoms did not differ by concussion history (Table 5). For males aged 16-17, a significantly higher proportion of those without a prior concussion reported headache (McNemar’s $\chi^2 = 69.4$, $p<0.001$), dizziness ($\chi^2 = 80.4$, $p<0.001$), fatigue ($\chi^2 = 37.4$, $p<0.001$), sleeping less than usual ($\chi^2 = 24.4$, $p<0.001$), irritability (χ^2 = 60.3, p<0.001), sadness (χ^2 = 50.7, p<0.001), and feeling slowed down (χ^2 = 68.2, p<0.001) compared to those with a previous history of concussion. A greater proportion of males aged 16-17 without a prior concussion reported trouble falling asleep, but this was not significant (χ^2 = 8.47, p = 0.004). Again based on overlapping confidence intervals, there was no significant difference in the proportion of females reporting specific symptoms by concussion history in either age group (Table 6).

Median symptom severity for males ranged from 1 to 2 out of 6 for all symptoms, regardless of age group or concussion history. Although median symptom severity for females ranged from 1 to 4, there were no significant differences by concussion history for any symptom.

Clinical reference values for ImPACT composite scores and total symptom scores are presented in Table 7. Clinical reference values are delineated based on performance being one standard deviation (SD) (16th percentile), 1.5 SDs (7th percentile), and 2 SDs (2nd percentile) below the mean, with stratification by age and sex. To use the table, clinicians look up raw scores for each of the composites and are able to determine if performance falls below same-age and same-sex peers.

Discussion

The purpose of this study was to examine population-specific psychometric properties of the ImPACT test in the context of elite youth ice hockey. Overall, ImPACT scores were consistent with those published for collegiate athletes with and without a history of concussion (Broglio et al, 2006) and composite scores for our sample fell well within the "average" range of Index Score classifications based on

American normative data (ImPACT Applications, 2011). Moreover, the results of the present study support previous findings that suggest no lingering cognitive deficits with a history of concussion (Brooks et al, 2013; Theriault et al, 2011; Thornton et al 2008; Broglio et al, 2006; Iverson et al, 2006a; Bijur et al, 1996).

It has been shown that, with increasing age, there is improved performance on neurocognitive tests (Gioia et al, 2004; Maruff et al, 2004) and other concussion assessment tools that include cognitive components (Valovich Mcleod, Bay, Lam, & Chhabra, 2012). Our results support this to some degree. Players aged 16-17 scored better in visual motor processing speed and impulse control compared to players aged 13-15, but there were no other significant age differences.

Also contrary to previous findings (Covassin et al, 2006; Barr, 2003; Weiss, Kemmler, Deisenhammer, Fleischhacker, & Delazer, 2003), we demonstrated no sex-related differences in neurocognitive performance. This may reflect the limited number of female athletes in our sample, leading to an underestimation of the difference between males and females. Conversely, it may be the result of cultural influence. Studies have found significant cultural variations in neurocognitive test performance and symptom reporting following concussion (Shuttleworth-Edwards, Whitefiled-Alexander, Radloff, Taylor, & Lovell, 2009; Ferrari, Constantoyannis, & Papadakis, 2001). To account for such differences, population-based normative values for the ImPACT test are available for specific geographic regions (i.e., United States), but normative values for Canada have not yet been established. As a result, we present reference tables that can be considered when interpreting ImPACT performance in elite Canadian adolescent hockey players. Additionally, other cultural differences are not well accounted for in published values. For example, the sport culture surrounding elite level ice hockey could affect male and female athletes in a similar fashion, which may induce their neurocognitive test scores and symptom reporting to be more similar to each other than they would be in the general population. Although such differences have not been empirically investigated, this may account for the present findings and represents a potentially important avenue of future research.

Consistent with previous studies (Kontos et al, 2012; Schneider et al 2010; Shehata et al, 2009; Covassin et al 2006), female players reported a greater total symptom score than males, although there was no effect of previous concussion. In the present study, concussion history was treated as a dichotomous variable (i.e., yes or no), and there is some evidence that athletes with as many as two previous concussions do not report increased symptoms (Moser et al, 2005; Iverson, Brooks, Lovell, & Collins, 2006b), whereas those with three or more concussions do have greater symptom ratings (Iverson et al, 2012; Thornton et al, 2008). The effect of previous concussion in the present study may have been underestimated; therefore, additional analyses examining the relationship between concussion history and symptom scores were conducted and are reported elsewhere (Brooks et al, 2013).

In a previous study examining baseline symptom endorsement among youth ice hockey players, Schneider et al. (2010) used the symptom scale of the Sport Concussion Assessment Tool (SCAT), which is a 24-item scale with severity ratings from 0-6. The authors demonstrated that the most commonly reported symptoms for 13-17 year old female players and 11-14 year old male players were fatigue, headache, trouble falling asleep, and difficulty concentrating (Schneider et al, 2010). Similarly, the present study identified trouble falling asleep and fatigue as two of the most commonly endorsed symptoms. Players also reported similar numbers of symptoms at baseline (2-4 without a previous of concussion, 2-21 with previous concussion) as in the Schneider et al (2010) study. Of note, the symptoms most frequently reported in this study represent variable state characteristics that can be expected to fluctuate, especially for youth athletes who are attending school and training for sport (i.e., fatigue and sleep-related symptoms). It is therefore unsurprising that these symptoms would be present, and reflects the need to accurately catalogue baseline symptoms in this population to aide in post-concussion management decisions.

Using the ImPACT test, Covassin et al (2006) reported that, at the collegiate level, female athletes were more likely than male athletes to endorse symptoms including trouble falling asleep, sleeping less than usual, and fatigue. Consistent with these findings, a slightly greater proportion of females than males endorsed trouble falling asleep, sleeping less than usual, and fatigue in the present study. As also reported by Covassin and colleagues (2006), participants in our study generally rated baseline symptoms in the mild range (i.e., 1-2 on a 0-6 scale). The results of this study are therefore congruent with other studies conducted in youth and young adult athlete populations (Schneider et al, 2010; Shehata et al, 2009; Lovell, Iverson, Collins, Podell, Johnston, Pardini et al, 2006).

It is interesting that, compared to those with a history of concussion, a significantly higher proportion of males aged 16-17 without a concussion reported headache, dizziness, fatigue, sleeping less than usual, irritability, sadness, and feeling slowed down. This could be a function of previously concussed players being more cautious when reporting their symptoms, for fear of being precluded from playing hockey. Concussion underreporting has been acknowledged as a limitation in athlete populations (Macciocchi & Broglio, 2012; Nelson & Doane, 2012; Sye, Sullivan & McCrory, 2006; Williamson & Goodman, 2006; McCrea, Hammeke, Olsen, Leo, & Guskiewicz, 2004). Players are particularly reluctant to report symptoms when they believe that they will be withheld from participating; McCrea and colleagues (2012) found that 41% of high school football players did not report potential concussions so as not to be removed from competition. At baseline, players in our study may have underreported symptoms because of concerns over playing time or additional scrutiny from coaches during the season. It could also be a function of regression to the mean after potentially having undergone multiple prior assessments.

A major issue facing the field of sport neuropsychology is the utility of comparing post-injury scores to individual pre-season baseline values. There is conflicting evidence regarding the reliability of the ImPACT test. Elbin, Schatz, and Covassin (2011) found scores to be stable over a one year period in a sample of adolescent athletes, whereas others have shown that reliability decreases over time (Broglio et al., 2007; Iverson et al., 2003). For example, Broglio et al. (2007) demonstrated that, in a sample of healthy individuals, intraclass correlations (ICC) for ImPACT indices ranged from 0.15 to 0.39 between a baseline assessment and a reassessment 45 days later; between day 45 and day 50, ICCs ranged from 0.39 to

0.61. Given this inconsistent evidence, and the test's vulnerability to self-report bias on a subjective rating scale, individualized baseline testing is not recommended by some researchers in current concussion management guidelines (Kirkwood, Randolph, & Yeates, 2009; McCrory, Meeuwisse, Aubry, Cantu, Dvorak, Echemendia, et al., 2012). As well, baseline testing is not always possible due to limited funding and personnel. As an alternative to baseline testing, we suggest that clinicians may find population normative values to be acceptable for informing concussion management decisions (Echemendia, Bruce, Bailey, Sanders, Arnett, & Vargas, 2012). Of course, it is important to remember that brief computerized testing does not constitute a full neuropsychological assessment, is only one aspect of post-concussion assessment, and medical decision-making is best informed using a multifaceted clinical approach.

Limitations

There are a number of limitations to this study that must be acknowledged. First, retrospective concussion reporting is subject to recall bias, particularly when concussion may have occurred months or years prior to data collection. Youth athletes may have difficulty recalling injuries, or may not know their medical history, therefore resulting in potential misclassification based on number of previous concussions. Conducting our analyses with concussion as a dichotomous variable would have reduced the effect of misclassification for those with multiple injuries, but it is possible that athletes incorrectly identified as having no previous concussion led to an underestimation of the effect of concussion on ImPACT scores.

Moreover, we were unable to account for athletes who may have previously completed the ImPACT test. The alternating forms built into the program should reduce the risk of practice effects, but it is possible that simply having experience with the test itself could have biased individual scores toward better performance.

Second, this study included a relatively small sample of female athletes and significant differences between males and females may have gone undetected as a result. Furthermore, very few female players reported three or more previous concussions, limiting our ability to examine the effect of multiple concussions on ImPACT scores in this group.

Finally, administering the ImPACT test in a group setting does not mirror the ideal conditions of clinical practice, and thus the results should be interpreted with caution. Moser and colleagues (2011) demonstrated that athletes who complete ImPACT in a group setting tend to perform more poorly on cognitive indices, but not symptom reporting, compared to those who are tested individually. However, as composite scores for our sample fell well within the "average" range of classifications based on American normative data, and baseline testing for team sports in Canada is commonly done in groups, our results are still applicable to our target population.

Overall, the results of this study may not be generalizable to athletes in different age groups, non-elite skill levels, or different sports.

Conclusions

This study provides reference baseline values for the ImPACT test battery for elite youth ice hockey players. Although females had greater overall symptom ratings than males, there were no other sex- or age-related differences in neurocognitive performance, contrary to previously published literature. There was also no effect of previous concussion on test scores.

In the absence of Canadian normative values for ImPACT, our results may be clinically useful when managing sport-related concussion. Clinicians are cautioned that the interpretation of individual baseline test scores may be of limited benefit in concussion management settings, and using population normative values may be sufficient to guide clinical decision-making.

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Table 1. Participant characteristics.

	Males (n = 591) Frequency (%) or Median (range)	**Females (n = 113) Frequency (%) or Median (range)**
Age	15 (13-17)	15 (13-17)
Competitive level		
AAA	337 (57.0)	113 (100.0)
AA	255 (43.0)	-
Reported previous concussion	222 (37.6)	32 (28.3)
1	147 (24.9)	18 (15.9)
2 or more	75 (12.7)	14 (12.4)
Missing	40 (6.8)	10 (8.8)
Reported attention deficit or learning disability	19 (3.2)	5 (4.4)

Table 2. Baseline composite scores by sex and age.

		Raw Composite scores Median (range) Mean (SD)				
Sex	**Age**	**Verbal memory**	**Visual memory**	**Visual motor processing speed**	**Reaction time**	**Impulse control**
Male	**13-15** (n=388)	84.0 (63.0-100.0) 83.7 (9.4)	75.0 (48.0-98.0) 74.5 (12.2)	34.7 (23.4-50.6) 35.4 (6.0)	0.59 (0.47-0.88) 0.60 (0.08)	7.0 (1.0-23.0) 8.3 (5.0)
	16-17 (n=203)	85.0 (56.0-100.0) 84.6 (9.6)	76.0 (46.0-97.0) 74.1 (12.5)	38.1 (24.8-51.4) 38.3 (5.9)	0.57 (0.45-0.96) 0.59 (0.09)	6.0 (1.0-22.0) 7.0 (4.6)
Female	**13-15** (n=70)	86.5 (51.0-100.0) 84.4 (10.6)	74.0 (47.0-100.0) 75.4 (13.7)	37.8 (13.5-50.7) 36.4 (7.0)	0.59 (0.45-0.88) 0.60 (0.08)	7.0 (0-21.0) 8.1 (4.9)
	16-17 (n=43)	89.0 (68.0-100.0) 88.4 (8.3)	79.0 (44.0-100.0) 77.9 (12.1)	38.8 (22.5-52.1) 39.3 (6.2)	0.56 (0.44-0.72) 0.57 (0.07)	6.0 (0-21.0) 6.5 (4.3)
		Age- and Sex-Adjusted Composite T scores Median (range) Mean (SD)				
Sex	**Age**	**Verbal memory**	**Visual memory**	**Visual motor processing speed**	**Reaction time**	**Impulse control**
Male	**13-15** (n=388)	51.5 (29.0-80.0) 51.9 (10.7)	50.3 (20.0-80.0) 50.5 (10.1)	48.4 (20.0-80.0) 48.9 (9.9)	54.1 (20.0-80.0) 50.7 (9.4)	48.2 (27.0-80.0) 48.2 (9.6)
	16-17 (n=203)	50.5 (20.0-73.0) 50.6 (9.6)	49.7 (20.0-80.0) 49.5 (10.9)	48.7 (20.0-70.0) 48.2 (8.5)	51.0 (20.0-70.0) 50.3 (8.7)	46.7 (27.0-64.8) 46.5 (8.7)
Female	**13-15** (n=70)	49.4 (20.0-69.0) 47.8 (11.4)	51.3 (30.0-80.0) 52.5 (12.3)	48.8 (20.0-70.0) 47.0 (12.2)	49.5 (27.0-73.0) 49.8 (9.5)	46.7 (27.0-73.0) 45.9 (10.3)
	16-17 (n=43)	51.5 (32.0-80.0) 54.2 (12.0)	54.1 (32.4-80.0) 54.4 (9.8)	48.0 (20.0-73.0) 48.8 (9.3)	50.3 (33.5-73.0) 49.3 (9.7)	46.4 (27.0-73.0) 48.1 (10.0)

Table 3. Baseline composite scores for boys by age and self-reported concussion history.

		Composite score Median (range) Mean (SD)					
Number of previous concussions	**Age**	**Verbal memory**	**Visual memory**	**Visual motor processing speed**	**Reaction time**	**Impulse control**	**Total symptoms**
0	**13-15** (n=255)	84.0 (65.0-100) 90.0 (9.0)	75.0 (49.0-98.0) 78.7 (13.4)	34.8 (23.6-49.1) 40.0 (7.0)	0.58 (0.48-0.88) 0.56 (0.07)	7.0 (1.0-23.0) 6.8 (4.3)	2 (0-31) 6.4 (7.6)
	16-17 (n=114)	85.0 (62.0-100) 84.9 (9.1)	77.0 (50.0-99.0) 75.5 (12.1)	38.9 (24.4-51.2) 38.2 (5.9)	0.57 (0.47-1.05) 0.59 (0.10)	6.0 (1.0-22.0) 6.6 (4.4)	4 (0-31) 5.6 (6.9)
1	**13-15** (n=93)	84.0 (61.0-100) 87.1 (10.1)	72.0 (45.0-99.0) 72.9 (9.7)	34.2 (23.4-56.0) 36.3 (4.1)	0.59 (0.30-0.89) 0.59 (0.05)	9.0 (1.0-30.0) 7.0 (4.2)	2 (0-29) 10.4 (7.9)
	16-17 (n=54)	87.0 (56.0-99.0) 84.4 (10.5)	75.0 (45.0-95.0) 71.7 (13.4)	37.7 (24.8-52.1) 38.1 (5.7)	0.56 (0.45-0.75) 0.58 (0.06)	7.0 (2.0-24.0) 8.1 (5.2)	4 (0-37) 6.6 (8.5)
2 or more	**13-15** (n=40)	84.5 (61.0-100) 83.8 (9.6)	78.5 (48.0-95.0) 76.6 (12.7)	35.0 (13.7-50.6) 35.4 (6.5)	0.59 (0.50-0.81) 0.60 (0.06)	6.0 (2.0-21.0) 7.6 (4.7)	5 (0-51) 9.2 (10.7)
	16-17 (n=35)	85.0 (53.0-100) 84.7 (9.8)	76.0 (46.0-95.0) 73.3 (12.2)	36.7 (26.2-51.7) 38.6 (6.4)	0.58 (0.48-0.79) 0.59 (0.07)	6.0 (2.0-16.0) 6.7 (3.7)	6 (0-50) 8.5 (10.4)

Table 4. Baseline composite scores for girls by age and self-reported concussion history.

		Composite score Median (range) Mean (SD)					
Number of previous concussions	**Age**	**Verbal memory**	**Visual memory**	**Visual motor processing speed**	**Reaction time**	**Impulse control**	**Total symptoms**
0	**13-15** (n=56)	87.0 (64.0-100) 86.0 (9.2)	74.0 (47.0-100) 75.4 (14.3)	38.1 (13.5-50.7) 37.0 (7.0)	0.59 (0.45-0.73) 0.59 (0.07)	6.0 (0-25.0) 8.5 (5.4)	4 (0-40) 8 .1 (11.0)
	16-17 (n=25)	93.0 (68.0-100) 84.0 (9.3)	79.0 (44.0-100) 75.3 (11.6)	40.7 (22.5-52.1) 35.4 (5.9)	0.53 (0.49-0.72) 0.60 (0.08)	6.0 (1.0-21.0) 8.1 (4.8)	4 (0-30) 4.1 (6.0)
1	**13-15** (n=11)	80.0 (51.0-99.0) 78.1 (13.8)	70.0 (52.0-85.0) 69.6 (10.7)	30.9 (24.7-46.5) 33.5 (7.4)	0.61 (0.50-0.88) 0.63 (0.11)	7.0 (1.0-19.0) 8.4 (5.2)	4 (0-30) 8.5 (12.4)
	16-17 (n=7)	91.0 (71.0-100) 82.8 (9.4)	74.0 (55.0-82.0) 71.6 (13.0)	36.0 (31.1-41.6) 35.4 (6.1)	0.59 (0.52-0.66) 0.61 (0.10)	6.0 (1.0-13.0) 9.3 (5.3)	8 (2-25) 4.3 (6.0)
2 or more	**13-15** (n=3)	83.0 (61.0-88.0) 77.3 (14.4)	91.0 (75.0-97.0) 87.7 (11.4)	34.4 (29.0-37.7) 33.7 (4.4)	0.64 (0.56-0.71) 0.64 (0.08)	7.0 (2.0-7.0) 5.3 (2.9)	33 (1-38) 24.0 (20.1)
	16-17 (n=11)	88.0 (78.0-92.0) 85.5 (4.3)	82.0 (61.0-91.0) 79.3 (10.4)	37.9 (30.6-48.7) 39.7 (5.2)	0.62 (0.44-0.66) 0.59 (0.07)	4.0 (0-17.0) 5.5 (4.5)	13 (1-34) 17.5 (10.8)

Table 5. Baseline symptoms reported by males (excludes males with missing concussion history).

	Males (age 13-15)				**Males (age 16-17)**			
	No previous concussion n = 214		**Previous concussion n = 148**		**No previous concussion n = 100**		**Previous concussion n = 189**	
Symptom	Proportion reporting symptom (95% CI)	Severity score Median (IQR)	Proportion reporting symptom (95% CI)	Severity score Median (IQR)	Proportion reporting symptom (95% CI)	Severity score Median (IQR)	Proportion reporting symptom (95% CI)	Severity score Median (IQR)
Headache	16.4 (11.4, 21.4)	2 (1-3)	16.2 (10.3, 22.1)	2 (1,3)	22.0 (13.9, 30.1)	1 (1-1)	3.2 (0.7, 5.7)	1 (1-3)
Nausea	0.9 (0, 2.2)	2 (1-2)	3.4 (0.5, 6.3)	1 (1-1)	1.0 (0, 3.0)	1 (1-1)	1.6 (0, 3.4)	1 (1-3)
Vomiting	4.2 (1.5, 6.9)	1 (1-2)	3.4 (0.5, 6.3)	2 (1-2)	1.0 (0, 3.0)	1 (1-1)	1.6 (0, 3.4)	2 (1-3)
Balance problems	11.7 (7.4, 16.0)	1 (1-2)	8.8 (4.2, 13.4)	2 (1-2)	10.0 (4.1, 15.9)	1 (1-3)	5.3 (2.1, 8.5)	1 (1-1)
Dizziness	10.3 (6.2, 14.4)	1 (1-2)	9.5 (4.8, 14.2)	2 (2-2)	11.0 (4.9, 17.1)	1 (1-2)	2.6 (0.3, 4.9)	2 (1-2)
Fatigue	23.4 (17.7, 29.1)	2 (1-2)	23.0 (16.2, 29.8)	2 (1-2)	34.0 (24.7, 43.3)	2 (1-2)	12.2 (7.5, 16.9)	1 (1-2)
Trouble falling asleep	36.4 (30.0, 42.9)	1 (1-2)	38.5 (30.7, 46.3)	1 (1-2)	54.0 (44.2, 63.8)	2 (1-3)	21.7 (15.8, 27.6)	2 (1-2)
Sleeping more than usual	6.5 (3.2, 9.8)	2 (2-3)	9.5 (4.8, 14.2)	1 (1-2)	14.0 (7.2, 20.8)	2 (1-3)	5.8 (2.5, 9.1)	2 (1-2)
Sleeping less than usual	28.0 (22.0, 34.0)	2 (1-2)	26.4 (19.3, 33.5)	2 (1-3)	36.0 (26.6, 45.4)	2 (1-3)	18.5 (13.0, 24.0)	2 (1-3)
Drowsiness	9.8 (5.8, 13.8)	1 (1-2)	7.4 (3.2, 11.6)	1 (1-2)	9.0 (3.4, 14.6)	1 (1-2)	5.3 (2.1, 8.5)	2 (1-3)
Sensitivity to light	21.0 (15.5, 26.5)	1 (1-2)	16.2 (10.3, 22.1)	2 (1-2)	27.0 (18.3, 35.7)	2 (1-2)	14.3 (9.3, 19.3)	1 (1-2)
Sensitivity to noise	6.1 (2.9, 9.3)	1 (1-2)	6.1 (2.2, 10.0)	1 (1-2)	11.0 (4.9, 17.1)	1 (1-2)	4.8 (1.8, 7.9)	1 (1-1)
Irritability	10.7 (6.6, 14.8)	1 (1-1)	5.4 (1.8, 9.0)	1 (1-2)	21.0 (18.3, 29.0)	1 (1-2)	6.9 (3.3, 10.5)	1 (1-2)
Sadness	28.0 (22.0, 34.0)	1 (1-2)	21.0 (14.4, 27.6)	2 (1-2)	24.0 (15.6, 32.4)	2 (1-2)	10.1 (5.8, 14.4)	1 (1-2)
Nervousness	6.1 (2.9, 9.3)	1 (1-2)	6.1 (2.2, 10.0)	1 (1-2)	10.0 (4.1, 15.9)	1 (1-2)	5.3 (2.1, 8.5)	2 (1-2)
Feeling more emotional	7.9 (4.3, 11.5)	1 (1-2)	6.1 (2.2, 10.0)	2 (1-3)	15.0 (8.0, 22.0)	2 (1-2)	10.1 (5.8, 14.4)	1 (1-2)
Numbness or tingling	5.1 (2.2, 8.1)	1 (1-2)	5.4 (1.8, 9.0)	1 (1-3)	4.0 (0.2, 7.8)	2 (1-3)	1.6 (0, 3.4)	1 (1-2)
Feeling slowed down	3.7 (1.2, 6.2)	2 (1-2)	2.7 (0.1, 5.3)	1 (1-2)	18.0 (10.5, 25.5)	2 (1-2)	5.3 (2.1, 8.5)	1 (1-1)
Feeling “foggy”	12.6 (8.2, 17.1)	1 (1-2)	10.1 (5.3, 15.0)	1 (1-2)	12.0 (5.6, 18.4)	1 (1-2)	6.9 (3.3, 10.5)	1 (1-2)
Difficulty concentrating	21.0 (15.5, 26.5)	1 (1-2)	20.3 (13.8, 26.8)	2 (1-3)	26.0 (17.4, 34.6)	1 (1-3)	12.7 (8.0, 17.5)	1 (1-2)
Difficulty remembering	13.1 (8.6, 17.6)	1 (1-2)	8.8 (4.2, 13.4)	1 (1-2)	13.0 (6.4, 19.6)	2 (1-2)	7.9 (4.1, 11.8)	1 (1-2)
Visual problems	8.9 (5.1, 12.7)	1 (1-2)	6.1 (2.2, 10.0)	1 (1-1)	7.0 (2.0, 12.0)	1 (1-2)	1.6 (0, 3.4)	1 (1-2)

Table 6. Baseline symptoms reported by females (excludes females with missing concussion history).

	Females (age 13-15)				**Females (age 16-17)**			
	No previous concussion n = 32		**Previous concussion n = 30**		**No previous concussion n = 24**		**Previous concussion n = 17**	
Symptom	Proportion reporting symptom (95% CI)	Severity score Median (IQR)	Proportion reporting symptom (95% CI)	Severity score Median (IQR)	Proportion reporting symptom (95% CI)	Severity score Median (IQR)	Proportion reporting symptom (95% CI)	Severity score Median (IQR)
Headache	28.1 (12.5, 43.7)	3 (2-4)	20.0 (5.7, 34.3)	3 (1-4)	37.5 (18.1, 56.9)	2 (1-3)	29.4 (7.7, 51.1)	4 (4-4)
Nausea	0	-	0	-	0	-	0	-
Vomiting	3.1 (0, 9.1)	2 (2-2)	6.7 (0, 15.7)	2 (1-2)	0	-	5.9 (0, 17.1)	1 (1-1)
Balance problems	9.4 (0, 19.5)	1 (1-2)	13.3 (1.2, 25.5)	2 (2-3)	16.7 (1.8, 31.6)	2 (1-2)	17.6 (0, 35.7)	1 (1-1)
Dizziness	15.6 (3.0, 28.2)	2 (1-2)	10.0 (0, 20.7)	3 (2-4)	4.2 (0, 12.2)	1 (1-1)	17.6 (0, 35.7)	1 (1-2)
Fatigue	34.4 (17.9, 50.9)	2 (1-2)	40.0 (22.5, 57.5)	2 (2-4)	50.0 (30.0, 70.0)	4 (2-4)	23.5 (3.3, 43.7)	2 (2-3)
Trouble falling asleep	34.4 (17.9, 50.9)	2 (1-2)	33.3 (16.4, 50.2)	3 (2-5)	58.3 (38.6, 78.0)	2 (1-2)	64.7 (42.0, 87.4)	2 (1-4)
Sleeping more than usual	6.3 (0, 14.7)	4 (2-5)	3.3 (0, 9.7)	2 (2-2)	0	-	0	-
Sleeping less than usual	37.5 (20.7, 54.3)	2 (1-3)	36.7 (19.5, 54.0)	3 (1-4)	50.0 (30.0, 70.0)	2 (2-4)	52.9 (29.2, 76.6)	2 (1-3)
Drowsiness	6.3 (0, 14.7)	2 (2-2)	10.0 (0, 20.7)	1 (1-5)	20.8 (4.6, 37.0)	2 (1-2)	5.9 (0, 17.1)	1 (1-1)
Sensitivity to light	18.8 (5.3, 32.3)	2 (2-3)	26.7 (10.9, 42.5)	3 (1-4)	37.5 (18.1, 56.9)	1 (1-2)	17.6 (0, 35.7)	3 (1-4)
Sensitivity to noise	9.4 (12.5, 43.7)	1 (1-2)	10.0 (0, 20.7)	2 (1-2)	20.8 (4.6, 37.0)	2 (1-2)	5.9 (0, 17.1)	1 (1-1)
Irritability	18.8 (5.3, 32.3)	2 (2-2)	20.0 (5.7, 34.3)	4 (1-4)	12.5 (0, 25.7)	2 (2-4)	23.5 (3.3, 43.7)	2 (1-3)
Sadness	15.6 (3.0, 28.2)	2 (1-2)	40.0 (22.5, 57.5)	1 (1-2)	33.3 (14.4, 52.2)	2 (1-3)	29.4 (7.7, 51.1)	1 (1-3)
Nervousness	0	-	6.7 (0, 15.7)	3 (2-4)	12.5 (0, 25.7)	2 (1-2)	5.9 (0, 17.1)	2 (2-2)
Feeling more emotional	9.4 (12.5, 43.7)	2 (1-4)	23.3 (8.2, 38.4)	1 (1-4)	25.0 (7.7, 42.3)	2 (1-2)	23.5 (3.3, 43.7)	2 (1-2)
Numbness or tingling	6.3 (0, 14.7)	2 (1-2)	10.0 (0, 20.7)	2 (1-5)	4.2 (0, 12.2)	4 (4-4)	0	-
Feeling slowed down	15.6 (3.0, 28.2)	1 (1-2)	16.7 (3.4, 30.1)	1 (1-3)	8.3 (0, 19.3)	2 (2-2)	5.9 (0, 17.1)	2 (2-2)
Feeling “foggy”	9.4 (12.5, 43.7)	1 (1-2)	16.7 (3.4, 30.1)	1 (1-2)	12.5 (0, 25.7)	1 (1-2)	5.9 (0, 17.1)	1 (1-1)
Difficulty concentrating	28.1 (12.5, 43.7)	2 (2-2)	43.3 (25.6, 61.0)	2 (1-3)	45.8 (25.9, 65.7)	2 (2-3)	35.3 (12.6, 58.0)	1 (1-2)
Difficulty remembering	6.3 (0, 14.7)	2 (1-3)	23.3 (8.2, 38.4)	1 (1-3)	12.5 (0, 25.7)	2 (1-4)	41.2 (17.8, 64.6)	1 (1-2)
Visual problems	9.4 (12.5, 43.7)	2 (1-3)	20.0 (5.7, 34.3)	2 (1-3)	12.5 (0, 25.7)	2 (1-3)	5.9 (0, 17.1)	1 (1-1)

Table 7. Reference values for ImPACT performance in elite Canadian hockey players.

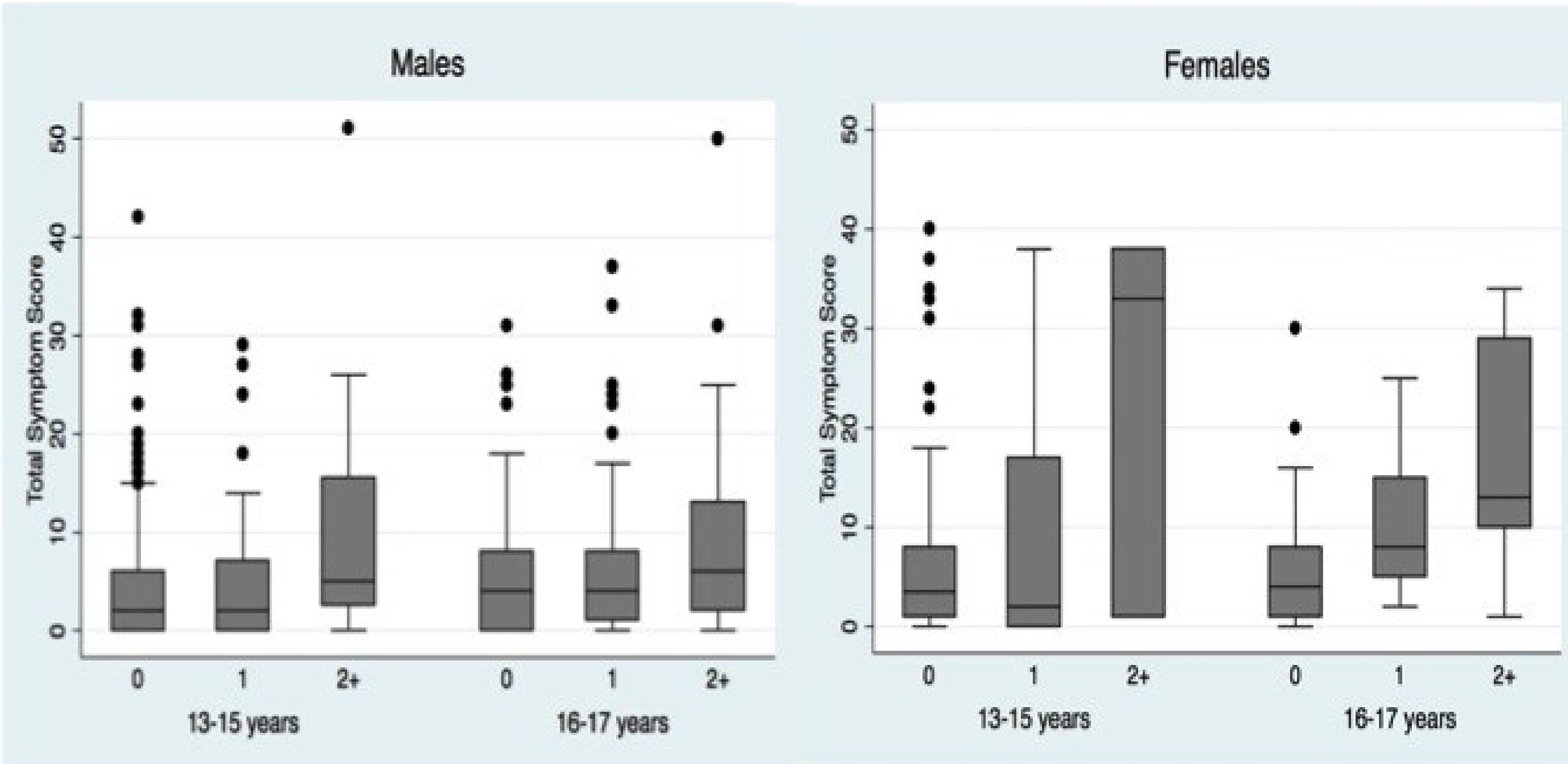
Sex	Age group	ImPACT Score[1]	≤16th percentile (≤ 1SD)	≤7th percentile (≤1.5SD)	≤2nd percentile (≤2SD)
Males	13-15	Verbal Memory	73.0	69.0	65.0
		Visual Memory	61.0	55.0	49.0
		Visual Motor	29.6	27.1	24.1
		Reaction Time	0.68	0.75	0.84
		Impulse Control	13.0	17.0	21.2
		Total Symptom	8.0	13.0	26.5
	16-17	Verbal Memory	75.0	70.3	59.2
		Visual Memory	58.0	54.0	47.0
		Visual Motor	32.0	30.1	26.3
		Reaction Time	0.64	0.69	0.82
		Impulse Control	10.4	14.0	21.0
		Total Symptom	10.0	15.9	25.7
Females	13-15	Verbal Memory	74.4	63.9	55.2
		Visual Memory	60.0	55.0	48.3
		Visual Motor	28.2	26.4	16.8
		Reaction Time	0.66	0.72	0.82
		Impulse Control	13.6	17.1	21.0
		Total Symptom	17.5	33.0	39.6
	16-17	Verbal Memory	79.1	74.3	68.0
		Visual Memory	67.0	57.1	44.0
		Visual Motor	32.8	31.1	22.5
		Reaction Time	0.66	0.70	0.72
		Impulse Control	11.0	13.0	21.0
		Total Symptom	15.7	21.8	30.0

Table note. [1]Because statistical differences were not found based on the number of prior concussions, reference values for composite scores include all participants. However, due to differences based on number of prior concussions, only those with zero previous concussions are included in the reference values for symptom ratings. SD=standard deviation.

Figure legends

Figure 1. Total symptom score by age, sex, and concussion history.

Figure legend: In these figures, boxes contain the interquartile range (IQR), bisected by solid lines representing the median value. Whiskers identify the most extreme values within 1.5 IQR, and outliers are indicated by dots.


Males
Total Symptom Score
0
10
20
30
40
50
0
1
2+
0
1
2+
13-15 years
16-17 years
Females
Total Symptom Score
0
10
20
30
40
50
0
1
2+
0
1
2+
13-15 years
16-17 years